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By P. E. Brown and F. E. Allison

The determination of the nitrogen-carbon ratio in soils is now considered of much importance in fertility studies. Not only does it show the organic matter content of soils more accurately than the more or less arbitrary humus determinations, concerning which considerable difference of opinion exists, but it also throws some light on the rate at which decomposition processes are occurring.

When organic matter is applied, the nitrogen-carbon ratio of the soil is modified to a greater or less extent, depending on the ratio of these elements in the materials used. Stewart [1] has shown that the common humus-forming substances have a much wider ratio than soils and hence the effect of turning under corn stover, oats straw or manure in a soil would be to widen the nitrogen-carbon ratio. The same author has also shown that under normal conditions the nitrogen-carbon ratio of the soil has a tendency to become narrower as the age of the organic matter increases. Other investigators have noted the same narrowing of the nitrogen-carbon ratio in decomposing organic matter and have concluded that it is due to the greater ease with which the carbonaceous portion of the organic matter decomposes and disappears than the nitrogenous part. Furthermore, as the more actively decomposable portions of the organic matter are removed, the remainder consists of rather inert materials whose decomposition proceeds more slowly and with much more difficulty.

The presence, therefore, of a narrow nitrogen-carbon ratio in soils might be considered to show a deficiency in fresh organic matter and consequently a lack of the proper decomposition processes for the production of optimum amounts of available plant food. This is actually the case in humid soils. Experience has shown that if the ratio narrows beyond a point of about 1 to 10, crop yields may be reduced, evidently because of an in-

[1] Stewart, Robt., Quantitative relationships of carbon, phosphorus and nitrogen in soils. Bull., Ill. Agr. Expt. Sta. 145. (Stewart gives also a complete bibliography of investigations on nitrogen and carbon in soils.)

sufficient production of available nitrogen, phosphorus and potassium. On the other hand, if the ratio is 1 to 12 or above, bacterial activities apparently occur to a satisfactory extent and enough soluble plant food is produced for good crop growth.

This question now arises: When a soil shows a narrow nitrogen-carbon ratio and hence a lack of fresh organic matter, should materials of the widest possible ratio be chosen to supply the deficiency? In other words, would the bacterial activities and crop yields be benefited as much by additions of straw as by turning under a crop like clover which has a much narrower nitrogen-carbon ratio, but at the same time supplies more nitrogen?

It is commonly believed that clovers or other leguminous green manure crops are more valuable for supplying organic matter than straws or stover, but the latter may be applied more cheaply and if they will serve as well to increase bacterial activities and crop yields they should be used.

Obviously, the nitrogen content of the soil should be considered in choosing materials to increase the organic matter content. When nitrogen is lacking, should leguminous crops be employed because of the nitrogen which they supply? Would it not be quite as satisfactory to increase the organic matter content of the soil and the decomposition processes by using a cheaper material which would increase the fixation of nitrogen from the atmosphere? Would these cheaper materials exert a sufficiently greater effect on bacterial activities, especially on azofication or non-symbiotic nitrogen-fixation, to prove as valuable as the leguminous green manures?

In other words, would straws increase the nitrogen content of the soil sufficiently through azofication to keep the crop as well supplied with nitrogen as when the legumes are used? Again, would the nitrogen in the soil be made available as rapidly by the decomposition produced by the straws, as that element in the legumes is made available by the decomposition which they engender?

These questions arose from a consideration of the nitrogen-carbon ratio in soils and the experiments reported in the following pages were planned to answer them. Briefly, the purpose of this work was to study the influence on certain bacterial activities of materials of narrow and of wide nitrogen-carbon ratio, when applied to soils low in organic matter. The processes studied were those which are important from the standpoint of the decomposition of nitrogenous organic matter, namely, ammonification and nitrification, and that which concerns the increase in soil nitrogen namely, azofication or non-symbiotic nitrogen-fixation.

The comparative effects of these materials on the growth of oats in greenhouse pots were also studied in the attempt to ascertain whether the crop yields were affected in a similar manner to the bacterial processes. It was also sought to determine whether inexpensive materials of a narrow nitrogen-carbon ratio would not stimulate bacterial activities and, especially, increase the fixation by the soil of nitrogen from the atmosphere sufficiently to give as satisfactory yields as materials of a wider ratio.

THE PLAN OF THE EXPERIMENT

The soil chosen for this work was secured from one of the college experimental orchards and is classed by the Bureau of Soils as Miami sandy loam. It was low in organic matter and slightly acid in reaction, showing a lime requirement (according to the Veitch method) of 736 lbs. of calcium carbonate per acre of 2,000,000 lbs. of surface soil. Before the special treatments were made, therefore, sufficient calcium carbonate was applied to neutralize the acidity and bring the lime content of the soil up to two tons per acre.

After being thoroughly sieved and air-dried and receiving the lime as mentioned, the soil was filled into thirty-six earthenware pots in the greenhouse, at the rate of 36 pounds per pot.

The special treatments of the pots were as follows:

1-2—Check.
3-4—15 tons horse manure per acre.
5-6—15 tons cow manure per acre.
7-8—15 tons rotted manure per acre.
9-10—2½ tons oats straw per acre.
11-12—3 tons corn stover per acre.
13-14—2 tons timothy hay per acre.
15-16—4 tons cowpea hay per acre.
17-18—4 tons clover hay per acre.
19-20—Check.
21-22—15 tons horse manure per acre.
23-24—15 tons cow manure per acre.
25-26—15 tons rotted manure per acre
27-28—2½ tons oats straw per acre.
29-30—3 tons corn stover per acre.
31-32—2 tons timothy hay per acre.
33-34—4 tons cowpea hay per acre.
35-36—4 tons clover hay per acre.

Plots 19 to 36 were seeded to oats and the others were kept bare to allow of the taking of samples for bacteriological tests.

The rate of application of the materials used was based on farm conditions, approximately the same amounts being applied as if a maximum crop were grown and turned under in the soil or a heavy application of manure were made.

All of the materials were dried and ground before being applied, but the application of the manures was calculated on the wet basis while in all the other cases the dry basis was used. All applications were figured on the basis of 2,000,000 lbs. of soil per acre.

After mixing the materials thoroly with the soil, the oats were seeded and all received 100 c. c. of an infusion made by shaking for five minutes, fresh soil with water in the proportion of 100 grams per 200 c. c. of water. This was to supply a vigorous bacterial flora from the soil in its natural state in order that the decomposition of the various materials might proceed as rapidly as it would in the field. The optimum moisture content of the soil was determined and after the addition of the infusions sufficient additional water was supplied to bring the water content in each pot up to the optimum. The pots were then weighed and additions of water were made at regular intervals during the continuance of the experiment to maintain a constant weight. The oats were harvested just prior to maturity and were dried, ground and analyzed.

Samples were drawn for bacteriological tests once every two or three weeks and the ammonifying, nitrifying, and azofying or nitrogen-fixing powers of the soils were determined. The casein-fresh-soil method [2] and the dried blood-fresh-soil method were used for ammonification. The ammonium-sulfate-fresh-soil method served for nitrification and the mannite-fresh-soil and dextrose-fresh-soil methods were employed for azofication.[3] The samples for the bacteriological tests were drawn with the usual precautions to avoid contamination and thoro mixing was insured before the 100 gram portions were weighed out for the various tests. The moisture content of all the soils was determined at each sampling and the moisture content of the soils in all the tests was adjusted to two-thirds of the saturation point. In the nitrification tests the moisture content of the samples was kept up by additions of sterile water to weight every ten days. The incubation took place at room temperature which was fairly constant at 23-25° C. The incubation period varied as will be noted in the later discussions.

The ammonification determinations were made in all cases except one by the magnesium-oxide method. In one instance the aeration method of Potter and Snyder [4] was used.

The nitrate determinations were made by the phenoldisulfonic acid method and total nitrogen was estimated by the regular Kjeldahl method.

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[2] Brown, P. E., Methods for the bacteriological examination of soils. Rsch. Bull., Iowa Agr. Expt. Sta. 11. 1912.

[3] Lipman, J. G., Suggestions concerning the terminology of soil bacteria. Botan. Gaz., 51: 454. 1911.

[4] Potter, R. S. and Snyder, R. S., The determination of ammonia in soils. Rsch. Bull. Iowa Agr. Expt. Sta. 17; also Journ. Ind. & Eng. Chem. 73: 221. 1915.

THE EFFECT OF THE MATERIALS ADDED ON THE NITROGEN-CARBON RATIO IN THE SOIL

The nitrogen and the carbon content of the soil and of all the materials used was determined and the nitrogen-carbon ratio calculated. These results are given in table I.

TABLE I. NITROGEN AND CARBON IN SOIL AND IN MATERIALS USED

Materials Analyzed	Nitrogen Percent.	Carbon Percent.	Nitrogen-carbon Ratio
Soil	0.0988	1.3481	1 : 13.644
Horse manure	1.6468	38.7614	1 : 23.537
Cow manure	2.4176	36.6160	1 : 15.145
Rotted manure	2.4461	23.9047	1 : 9.772
Oats straw	.8590	38.1622	1 : 44.426
Corn stover	1.4762	39.8266	1 : 26.979
Timothy hay	.9727	38.1502	1 : 39.221
Cowpea hay	2.1852	42.1834	1 : 19.304
Clover hay	2.0564	41.3085	1 : 20.088

The soil used showed a satisfactorily wide ratio and hence the effects of the materials added cannot be expected to appear as definitely as might be the case did the soil itself contain a smaller amount of organic matter of a narrower ratio.

The rotted manure had the narrowest ratio of any of the materials employed and the oats straw the widest. The cow manure had a narrower ratio than the horse manure and the relative amounts of nitrogen and carbon in the legume hays were about the same as those in the horse manure.

TABLE II. NITROGEN CARBON RATIO IN SOILS AFTER TREATMENT

Pot No.	Treatment	Materials Added Gms.	N Added Gms.	C Added Gms.	Total N Gms.	Total C Gms.	N-C Ratio
1	Check	none	none	none	16.14	220.26	1 : 13.6
2	Check	none	none	none	16.14	220.26	1 : 13.6
3	Horse manure	78.19	1.29	30.31	17.43	250.57	1 : 14.4
4	Horse manure	78.19	1.29	30.31	17.43	250.57	1 : 14.4
5	Cow manure	59.63	1.44	21.84	17.59	242.10	1 : 13.8
6	Cow manure	59.63	1.44	21.84	17.59	242.10	1 : 13.8
7	Rotted manure	83.65	2.05	20.00	18.19	240.26	1 : 13.2
8	Rotted manure	83.65	2.05	20.00	18.19	240.26	1 : 13.2
9	Oats straw	40.85	0.35	15.59	16.50	235.85	1 : 14.3
10	Oats straw	40.85	0.35	15.59	16.50	235.85	1 : 14.3
11	Corn stover	49.02	0.72	19.52	16.87	239.79	1 : 14.2
12	Corn stover	49.02	0.72	19.52	16.87	239.79	1 : 14.2
13	Timothy hay	32.68	0.32	12.47	16.46	232.73	1 : 14.1
14	Timothy hay	32.68	0.32	12.47	16.46	232.73	1 : 14.1
15	Cowpea hay	65.36	1.43	27.57	17.57	247.83	1 : 14.1
16	Cowpea hay	65.36	1.43	27.57	17.57	247.83	1 : 14.1
17	Clover hay	65.36	1.34	27.00	17.49	247.26	1 : 14.1
18	Clover hay	65.36	1.34	27.00	17.49	247.26	1 : 14.1

Table II shows the amounts of nitrogen and carbon added to the soils in the various materials applied and the nitrogen-carbon ratio in the soils after the applications were made. All the materials applied widened the nitrogen-carbon ratio except the rotted manure, which narrowed it. This is in accord with the results in table I which showed that the rotted manure had a narrower ratio than the soil itself and hence might be expected to narrow the ratio in the soil. The oats straw widened the ratio more than any of the hays, particularly the legumes, which is what would be expected. The horse manure brought about a greater widening of the ratio than the other materials, greater even than those which themselves had a wider ratio. This is evidently due to the very much larger application of the horse manure than of the straw, stover, and hays.

The amounts of all the materials used were calculated as maximum field applications and hence it is interesting to note the relative influence of the different substances and consider them from the field standpoint. Rotted manure actually narrowed the ratio and may be considered as having the least effect on the decomposition processes; all the other materials increased the proportion of carbon to nitrogen and hence should increase bacterial activities to a much greater extent.

Among the straws and hays used, the wider the nitrogen-carbon ratio, the greater the widening of the ratio in the soil when they were applied. It might be expected, therefore, that the materials of the wider ratios would give greater effects on bacterial processes than those whose content in nitrogen and carbon was more nearly the same.

The changes in the nitrogen-carbon ratio in this soil, by the applications of these materials, were very much smaller, undoubtedly, than would have occurred if a soil of a narrower ratio had been chosen. It is apparent, however, that the ordinary humus-forming materials on the farm widen the nitrogen-carbon ratio of the soil, even when it is not extremely narrow. Hence they should be expected to increase bacterial activities to a beneficial extent, and also, as a consequence, the decomposition processes, the production of available plant food, and the fixation of nitrogen from the atmosphere.

THE AMMONIFICATION EXPERIMENTS

The experiment was started December 5, and the first sampling was made December 24, in order to allow time for decomposition to commence. Samplings were made approximately every two weeks, the dates being January 7, January 28, February 12, February 26, and March 12.

The results of the ammonification tests using casein and those secured with dried blood are considered separately, but general conclusions will be drawn from both lots of experiments. The incubation period in the case of casein was three and four days, while with the dried blood it was six and seven days.

THE AMMONIFICATION OF CASEIN

The results of the ammonification experiments with casein are given in table III and in table IV, they are reported in a summarized form. Where individual results were widely at variance with the general trend of the results as shown thruout the six samplings, they are omitted from the averages. The tests at the first three samplings were incubated four days and those on the remaining dates were incubated three days.

Very much larger amounts of ammonia were produced in the samples taken on January 7 than in the tests at other dates. This is probably due to an increase in room temperature to 29° C., which occurred while the samples were being incubated.

It will be seen in table III that for the most part the duplicate determinations agreed very satisfactorily, or at least much better than in the case of other tests with different nitrogenous materials.

The differences in ammonifying power between the different soils were not, however, very large, and it is very difficult in such cases to draw definite conclusions.

In general, it appears from table IV that horse manure, cow manure, and rotted manure favored the ammonifying bacteria to the greatest extent. Next in order came clover hay, corn stover, oats straw, cowpea hay, and timothy hay, respectively. In the case of the latter materials the differences were not large, and their relative effects varied greatly at the different samplings.

For the most part, however, all the materials increased the ammonifying power of the soil, according to the tests, and while in a few instances some depressing action was noted, the figures were not widely enough separated for the results to be conclusive.

Some depression in the ammonifying power of soils may occur immediately following the application of materials similar to those used in these experiments, but after such substances commence to decompose, any decrease in the activities of the ammonifying bacteria would hardly be expected. Some decomposition of all the materials used in this work had undoubtedly occurred prior to the making of any tests and hence it seems probable that the slight depressions noted should be considered merely as indications of the absence of any particular increasing action of the substances applied. The variations from the results with the check soils should in such a case be considered as due to experimental error, or accidental contamination. Much more distinctive results than those secured here must be obtained before

TABLE III. THE AMMONIFICATION OF CASEIN

Pot. No.	Lab. No.	I December 24		II January 7		III January 28		IV February 12		V February 26		VI March 12	
		Ammonia Mgs. N.	Av. Mgs. N.	Ammonia Mgs. N.	Av. Mgs. N.	Ammonia Mgs. N.	Av. Mgs. N.	Ammonia Mgs. N.	Av. Mgs. N.	Ammonia Mgs. N.	Av. Mgs. N.	Ammonia Mgs. N.	Av. Mgs. N.
1	1	82.32		100.94		85.63		84.38		88.69		92.39	
	2	92.47	87.54	104.72	102.84	89.29*	85.63	86.15	85.26	90.47	89.58	94.42	93.40
2	3	87.06		101.85		83.67		83.66		88.58		91.44	
	4	90.97	89.01	103.40	102.62	89.15*	83.67	85.99	84.82	90.37	89.47	94.69	93.05
3	5	90.29		105.57		92.05		87.04		92.75		96.31	
	6	90.97	90.63	104.72	105.14	94.22	93.13	85.99	86.51	92.16	92.45	95.50	95.90
4	7	89.76		103.83		90.28		89.89		92.75		98.48	
	8	84.05*	89.76	104.49	104.16	86.61	88.45	85.27	87.58	lost	92.75	94.42	96.45
5	9	86.08*		105.57		86.19		84.91		96.03		98.88	
	10	89.01	89.01	108.68	107.12	89.99	88.09	87.24	86.07	93.38	94.70	93.88	96.38
6	11	88.49		104.72		81.83*		85.09		92.75		98.34	
	12	89.99	89.24	104.49	104.60	85.73	85.73	85.27	85.18	92.75	92.75	94.42	96.38
7	13	88.49		103.83		90.17		85.09		91.26		94.01	
	14	89.01	88.75	105.81	104.82	87.31	88.74	86.87	85.98	92.75	92.00	86.02*	94.01
8	15	89.01		102.93		85.63		86.51		92.45		94.28	
	16	90.97	89.99	109.11	106.02	84.50	85.06	87.60	87.05	93.05	92.75	93.34	93.81
9	17	86.53		106.04		85.63		85.79		91.86		93.74	
	18	90.97	88.75	105.38	105.71	83.38	84.50	82.41	84.10	93.38	92.62	94.55	94.14
10	19	86.51		98.79		81.96		82.60		92.45		92.25	
	20	90.29	88.90	100.76	99.77	83.67	82.81	82.60	82.60	94.54	93.49	88.59	90.42
11	21	89.01		102.51		82.25		87.42		87.98		92.93	
	22	90.97	89.99	100.76	101.63	88.87	85.56	85.09	86.25	90.47	89.22	94.55	93.74
12	23	89.76		105.10		84.80		83.49		88.47		92.79	
	24	90.97	90.36	102.51	103.80	89.43	87.12	86.71	85.10	90.67	89.57	88.32*	92.79
13	25	92.17		102.32		86.61		86.87		89.18		90.90	
	26	88.14	90.25	105.10	103.71	82.53	84.52	84.02	85.44	88.58	88.88	89.81	90.35
14	27	89.54		104.25		84.38		86.71		92.45		93.20	
	28	88.49	89.01	97.70	100.97	78.73	82.55	84.54	85.62	92.16	92.30	89.27	91.23
15	29	85.55		105.10		78.59		85.27		91.56		91.72	
	30	85.55	85.55	99.21	102.25	78.55	78.57	84.45	84.81	88.47	90.01	96.04	93.88
16	31	89.54		105.51		78.59		85.99		91.26		87.78	
	32	89.54	89.54	107.83	106.67	80.14	79.36	88.29	87.14	lost	91.26	91.44	89.61
17	33	90.97		108.03		86.33		87.76		91.26		93.61	
	34	89.99	90.48	106.23	107.13	87.18	86.75	87.60	87.68	88.58	89.92	91.57	92.59
18	35	90.97		105.57		86.47		87.60		88.58		93.88	
	36	87.06	89.01	107.13	106.35	81.83*	86.47	85.99	85.78	88.47	88.52	92.52	93.20

* Results omitted from the averages.

TABLE IV. THE AMMONIFICATION OF CASEIN

Pot No.	Treatment	I		II		III	
		Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.
1	Check	87.54		102.84		85.63	
2	Check	89.01	88.27	102.62	102.73	83.67	84.65
3	Horse manure....	90.63		105.14		93.13	
4	Horse manure....	89.76	90.19	104.16	104.65	88.45	90.79
5	Cow manure......	89.01		107.12		88.09	
6	Cow manure......	89.24	88.39	104.60	105.86	85.73	86.91
7	Rotted manure...	88.75		104.82		88.74	
8	Rotted manure...	89.99	89.37	106.02	105.42	85.06	86.90
9	Oats straw.......	88.75		105.71		84.50	
10	Oats straw.......	88.90	88.82	99.77	102.74	82.81	83.65
11	Corn stover.......	89.99		101.63		85.56	
12	Corn stover.......	90.36	90.17	103.80	102.71	87.12	86.34
13	Timothy hay.....	90.25		103.71		84.52	
14	Timothy hay.....	89.01	89.63	100.97	102.34	82.55	83.53
15	Cowpea hay......	85.55		102.25		78.57	
16	Cowpea hay......	89.54	87.54	106.67	104.46	79.36	78.96
17	Clover hay........	90.48		107.13		86.75	
18	Clover hay........	89.01	89.74	106.35	106.74	86.47	86.61

Pot No.	Treatment	IV		V		VI	
		Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.
1	Check	85.26		89.58		93.40	
2	Check	84.82	85.04	89.47	89.52	93.05	93.22
3	Horse manure....	86.51		92.45		95.90	
4	Horse manure....	87.58	86.54	92.75	92.60	96.45	96.17
5	Cow manure......	86.07		94.70		96.38	
6	Cow manure......	85.18	85.62	92.75	93.72	96.38	96.38
7	Rotted manure...	85.98		92.00		94.01	
8	Rotted manure...	87.05	86.56	92.75	92.35	92.79	93.91
9	Oats straw.......	84.10		92.62		94.14	
10	Oats straw.......	82.60	83.35	93.49	93.05	90.42	92.28
11	Corn stover......	86.25		89.22		93.74	
12	Corn stover......	85.10	85.67	89.57	89.38	92.79	93.26
13	Timothy hay.....	85.44		88.88		90.35	
14	Timothy hay.....	85.62	85.53	92.30	90.59	91.23	90.79
15	Cowpea hay......	84.81		90.01		93.88	
16	Cowpea hay......	87.14	85.97	91.26	90.63	89.61	91.74
17	Clover hay.......	87.68		89.92		92.59	
18	Clover hay.......	85.78	86.73	88.52	89.22	93.20	92.89

the occurrence of any depressing action could be considered as the rule with the use of these materials.

In short, it seems safe to conclude that applications of humus forming materials increased the ammonifying power of soils as indicated by tests with the casein-fresh-soil method. The manures had a greater effect than straw, stover, or hays, and horse manure and cow manure showed much more influence than rotted manure. It must be recalled here that the becterial factor was the same in all the pots as the materials were all added in a dry condition and different effects were due, therefore, to differences in amounts added or in composition.

While the casein-fresh-soil method gives very satisfactory results from the standpoint of agreement of duplicates and because of ease of manipulation, it is apparent that some further modification will be necessary to make it possible for distinctive results to be secured with its use. The dried-blood-fresh-soil method, altho much more difficult to use, is evidently better suited for general soil studies and causes a wider difference to be shown in ammonifying power between soils differently treated.

Reference will again be made to the results with casein after the dried-blood experiments are considered.

THE AMMONIFICATION OF DRIED BLOOD

The samples drawn on the same dates as previously mentioned when the ammonifying power of the soils was tested with casein were used for ammonification tests with dried blood, except that no tests were made on January 7. An additional sampling was made, however, on March 24, so that six series of results were secured here. Thus there was provided a comparison of the two methods as well as additional data on the ammonifying power of the soils.

The results of the tests with dried blood are given in table V and the summarized results appear in table VI.

The incubation period for the first, third, and fifth sampling was seven days; for the fourth and sixth it was six days and in the second series one-half of the determinations were made on the fifth day and the duplicate half on the sixth day. This second series was distilled by the aeration method and this fact, together with the shorter incubation period, explains the low results.

It is commonly recognized that the magnesium oxide method for ammonia gives more than just the ammonia present as such in the soil, breaking down as it does certain amino-compounds and liberating ammonia from them. The aeration method liberates only the ammonia present as such in the soil. The manipulation of the aeration method is somewhat difficult, and especially to keep the entire 100 grams of soil used in each test in such motion as is necessary for accurate results, and hence it was not used for the other tests. The results with magnesium oxide may not be absolutely accurate for ammonia as such, therefore, but they are comparative at least, which, after all, is the main consideration in the ammonification studies reported in this work.

The duplicate determinations, as is usually the case with dried blood, did not agree very closely. This is the chief objection to the dried blood method and is due partly to the lack of uniformity in the composition of the dried blood and the difficulty of thoro mixing with the soil, and largely to the difficulty in dis-

TABLE V. THE AMMONIFICATION OF DRIED BLOOD

Pot. No.	Lab. No.	I December 24		II January 28		III February 12		IV February 26		V March 12		VI March 24	
		Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Mgs. N.	Ammonia Mgs. N.	Average Ngs. N.
1	1	75.31		29.09		lost		95.33*		52.57		57.73	
	2	78.83	77.07	67.71*	29.09	lost	.....	89.07*	.....	41.98	47.27	92.56*	57.73
2	3	87.05		25.90		lost		46.88		43.87		67.71	
	4	59.47	73.28	32.22	29.06	42.15	42.15	51.86	49.37	43.60	43.73	93.54*	67.71
3	5	92.63		25.11*		lost		58.31		57.19		91.17	
	6	96.24	94.43	50.95	50.95	62.52	62.52	91.71	75.01	73.71	65.45	93.74	92.45
4	7	102.90		37.70		lost		81.45		76.62		87.67	
	8	86.26	94.58	lost	37.70	78.36	78.36	81.16	81.30	97.96	87.29	113.09	100.38
5	9	116.58		33.55		lost		101.38		76.62		68.93	
	10	97.00	106.79	lost	33.55	52.34	52.34	89.37	95.36	71.18	73.90	83.95	76.44
6	11	93.12		47.08		lost		101.67		92.38		46.77*	
	12	70.43	81.77	72.31	59.69	75.53	75.53	108.12	104.89	74.58	83.48	100.39	100.39
7	13	93.44		44.71		lost		96.98		46.72		70.65	
	14	129.67	111.55	57.22	50.96	90.81	90.81	109.88	103.43	54.75	50.73	88.65	79.65
8	15	110.91		39.13		lost		105.48		95.92		111.74	
	16	102.12	106.51	73.13	56.13	73.21	73.21	119.25	112.36	73.90	84.91	88.04	99.89
9	17	78.63		44.04		lost		62.70		63.03		53.39	
	18	89.57	84.10	60.28	52.16	97.60	97.60	55.67	59.18	58.14	60.58	76.52	64.95
10	19	87.04		43.70		lost		78.23		55.15		81.60	
	20	84.16	85.60	40.32	42.01	51.20	51.20	87.31	82.77	94.97	74.56	91.39	86.44
11	21	83.91		48.10		lost		91.12		88.44		103.33	
	22	87.25	85.58	55.53	51.81	43.85	43.85	74.42	82.77	82.33	85.38	64.17	83.75
12	23	83.57		43.01		lost		79.99		66.97		78.87	
	24	84.29	83.43	59.26	51.13	68.74	68.74	66.80	73.38	81.14	74.07	51.25	65.06
13	25	112.09		52.85		lost		75.01		143.08		87.67	
	26	76.43	94.36	75.39	64.12	63.65	63.65	110.17	92.59	69.65	106.36	91.39	89.53
14	27	102.71		46.41		lost		108.41		152.72		83.95	
	28	107.40	105.05	73.43	59.92	67.05	67.05	132.14	120.27	51.07	101.89	87.08	85.51
15	29	88.60		33.91		lost		66.51		94.56		68.10	
	30	61.43	75.01	53.84	43.87	61.39	61.39	77.35	71.93	102.03	98.29	70.67	69.37
16	31	85.68		42.01		lost		77.65		122.01*		73.67	
	32	84.81	85.24	72.91	57.46	51.77	51.74	67.98	72.81	81.78	81.78	72.99	73.48
17	33	83.90		51.16		lost		79.40		52.70		65.17	
	34	78.84	81.37	50.14	50.65	57.43	57.43	89.37	84.38	58.82	55.76	62.82	63.99
18	35	92.53		40.00		lost		66.80		129.75		62.43	
	36	81.75	87.14	62.29	51.14	107.22*		67.68	67.24	106.11	117.93	88.85	75.64

* Results omitted from the averages.

TABLE VI. THE AMMONIFICATION OF DRIED BLOOD

Pot No.	Treatment	I Ammonia Mgs. N.	I Average Mgs. N.	II Ammonia Mgs. N.	II Average Mgs. N.	III Ammonia Mgs. N.	III Average Mgs. N.
1	Check	77.07		29.09		.....	
2	Check	73.28	75.14	29.06	29.07	42.15	42.15
3	Horse manure....	94.43		50.95		62.52	
4	Horse manure....	94.58	94.50	37.70	44.32	78.36	70.44
5	Cow manure......	106.74		33.55		52.34	
6	Cow manure......	81.77	94.28	59.69	46.62	75.53	63.43
7	Rotted manure...	111.55		50.96		90.81	
8	Rotted manure...	106.51	109.00	56.13	53.54	73.21	82.01
9	Oats straw.......	84.10		52.16		97.60	
10	Oats straw.......	85.60	84.85	42.01	47.08	51.20	74.40
11	Corn stover......	85.58		51.81		43.85	
12	Corn stover......	83.43	84.50	51.13	51.47	68.74	56.29
13	Timothy hay.....	94.36		64.12		63.65	
14	Timothy hay.....	105.05	99.70	59.62	62.02	67.05	65.35
15	Cowpea hay......	75.01		43.87		61.39	
16	Cowpea hay......	85.24	80.12	57.46	50.16	51.77	56.58
17	Clover hay.......	81.37		50.65		57.43	
18	Clover hay.......	87.14	84.25	51.14	80.89	.....	57.43

Pot No.	Treatment	IV Ammonia Mgs. N.	IV Average Mgs. N.	V Ammonia Mgs. N.	V Average Mgs. N.	VI Ammonia Mgs. N.	VI Average Mgs. N.
1	Check	.....		47.27		57.73	
2	Check	49.37	49.37	43.73	45.50	67.71	62.72
3	Horse manure....	75.01		65.45		92.45	
4	Horse manure....	81.30	78.15	87.29	76.37	100.38	96.41
5	Cow manure......	95.36		73.90		76.44	
6	Cow manure......	104.89	100.13	83.48	78.69	100.39	88.41
7	Rotted manure...	103.43		50.73		79.65	
8	Rotted manure...	112.36	107.89	84.91	67.82	99.89	89.77
9	Oats straw.......	59.18		60.58		64.95	
10	Oats straw.......	82.77	70.97	74.56	67.57	86.44	75.72
11	Corn stover......	82.77		85.38		83.75	
12	Corn stover......	73.38	78.07	74.07	79.72	65.06	74.40
13	Timothy hay.....	92.59		106.36		89.53	
14	Timothy hay.....	120.27	106.43	101.89	104.12	85.51	87.52
15	Cowpea hay......	71.93		98.29		69.37	
16	Cowpea hay......	72.81	72.37	81.78	90.03	73.48	71.42
17	Clover hay.......	84.38		55.76		63.99	
18	Clover hay.......	67.24	75.81	117.93	86.84	75.64	69.81

tilling because of foaming. In some instances where the results were clearly abnormal they were not included in the averages.

Considering now the results in table VI, it is apparent that the different materials affected quite differently the ammonifying power of the soils as determined by the dried blood method.

The effects of treatment were much more pronounced than with the casein method. There was in no case a decrease in ammonifying power, and hence the few slight depressions noted with the casein were evidently due to an absence of indications of effect rather than to an actual depression of ammonifying power.

Again, it appears that the manures favored the ammonifying process very largely. With only one exception the manures all showed greater effects on the ammonifying bacteria than any of the other materials. The rotted manure gave a greater influence than the cow or horse manure. It will be recalled that the rotted manure had the narrowest ratio of any of the materials and it gives here the greatest effect on the ammonifying power of the soil.

The general influence of the horse and cow manure was about the same, the horse manure having a slight advantage. Their nitrogen-carbon ratios were quite different, that of cow manure being much narrower than that of horse manure, so it appears here that the difference in ratio had little effect on the influence exerted by the materials on ammonification.

The most surprising results were those from the soils treated with timothy hay, which were about as high as those from the soils receiving rotted manure, and higher in almost every case than those from the soils where horse and cow manure were used. The timothy hay had a wide nitrogen-carbon ratio, very much wider than the other materials except the oats straw. It might seem, therefore, that materials of wide nitrogen-carbon ratio would exert as much effect on ammonification as those of a narrow ratio. When the results with oats straw are considered, however, it is found that the effects on the ammonifying bacteria were much less than the influence exerted by the manures and even less than the effect of the hays which had a narrower nitrogen-carbon ratio.

Practically the same situation obtained in the case of the corn stover, and the effect on the ammonifying bacteria was less than that exerted by the manures and hays, which had narrower ratios of nitrogen and carbon. It seems, therefore, that the nitrogen-carbon ratio in the common humus-forming materials was of very little influence on the extent of the action exerted on the ammonifying becteria.

The cowpea hay and clover hay uniformly exerted less influence on the ammonifying process than the manures and the timothy hay but they showed more effect than the oats straw and corn stover, altho the differences were not very great and there were some variations in effects shown at the different samplings.

It is apparent, therefore, that some other factors than the nitrogen-carbon ratio in the materials used in this work must be of more importance in determining the effect on the ammonifying bacteria. It is probable that the character of the chemical compounds present in the materials used would explain the variations noted, for the different substances are made up, of course, of very different chemical substances, and while these differences would not appear from the analyses for carbon and nitrogen, they are undoubtedly present and of much significance from the standpoint of effects on bacterial activities.

It will be recalled that the materials were all applied dry so that the variations noted were not due to the bacterial content of the substances. Of course, different quantities were used, amounts such as are common on the farm being employed. These differences in applications probably account partially for some of the results noted, such, for instance, as the greater effect of the manures, but inasmuch as the results are to be interpreted from the field standpoint it was necessary to make field applications and these differences in amounts are inherent in farm practice.

In general, therefore, it appears from these results that applications of the common humus-forming materials in maximum amounts employed on the farm, led to increases in the ammonifying power of the soil. Furthermore, these increases were apparently independent of the nitrogen-carbon ratio of the materials added and probably dependent on the chemical composition of the substances. Manures gave the greatest effects in most cases, altho the timothy hay used gave a greater influence than the horse or cow manure. In the field, under ordinary farm conditions, when the manures are applied in a fresh condition and teeming with bacteria, a greater effect of the manures on ammonification would be expected.

Similarly, while the rotted manure gave the greatest influence in these results, in the field, it is probable that the fresh manures would show more effect because of the actual bacteria added.

If the soil employed had possessed a narrower nitrogen-carbon ratio, the differences in the results might have been more pronounced, so that any conclusion from this work must be qualified by specifying *for this particular soil which possessed a satisfactorily wide nitrogen-carbon ratio.* With this qualification, then, the statement previously made may be accepted as a rather definite conclusion from these results, namely, that the nitrogen-carbon ratio of common humus-forming materials, used in maximum field applications, had little or no effect on the influence exerted by these substances on ammonification in *this particular soil.* The different effects were probably due to the variations in chemical composition of the materials used.

Comparing the results of the ammonification tests as a whole, using the casein and the dried blood methods, it is apparent that the latter allows of much greater differentiation between the ammonifying power of soils differently treated. The casein method permits of the securing of much better agreement among duplicate determinations, but this point is of minor importance to the securing of results distinguishing more widely between ammonification in different soils. Some further modification in the technique of the casein method may remedy the difficulty mentioned but until such a change is made, the dried blood method must be considered the most satisfactory.

THE NITRIFICATION EXPERIMENTS

To determine the effect of the various materials used in this work on the nitrifying power of the soil, samples secured on the dates previously mentioned were tested by the ammonium-sulfate-fresh-soil method as has been described. The tests on February 12 were incubated for 27 days and all the other tests were made in 28 days. The results of the determinations are given in table VII, and the average results appear in table VIII. A few of the results are omitted from the averages because of evident abnormality. It will be noted, however, that as a whole the duplicate determinations agreed very satisfactorily.

From table VIII it appears that the differences in nitrifying power were not pronounced. In general, however, the cowpea hay and clover hay had the greatest action on the nitrifiers and the manures a smaller effect, while the straws, stover, and timothy hay showed little influence on nitrification. The differences were too small to warrant definite conclusions in the case of the three latter materials, and hence the only statement which can be made is that these materials exerted practically no influence on nitrification. The small variations in the nitrifying power of the soils used in this work might have been increased by a longer incubation period. Possibly larger differences might have been found with variations in the method employed, but from the standpoint of these experiments it is apparent that the nitrogen-carbon ratio of the materials used had no effect on the influence of the substances on the nitrifying power of the soils. The effects of the materials were dependent probably, as in the case of ammonification, on the chemical compounds present in the materials.

It is interesting to note that the manure, which exerted the greatest effect on ammonification, showed also comparatively large effects on nitrification, while the legume hays, which showed smaller effects on ammonification than the manures, gave a greater influence on nitrification. Just why this should be is difficult to determine, as ordinarily materials which favor ammonification in field soils will favor also nitrification, unless the amounts of organic matter added are so large that nitrification is entirely inhibited. It seems to be a matter of considerable doubt at present whether it is possible to add sufficient organic matter to field soils to prevent nitrification. However that may be, it is apparent here that nitrification was not restricted by any of the maximum applications of the common materials used and ammonification was increased as described, hence it might be ex-

TABLE VII. THE NITRIFICATION OF AMMONIUM SULFATE

Pot No.	Lab. No.	I December 24 Nitrate Mgs. N.	I December 24 Average Mgs. N.	II January 7 Nitrate Mgs. N.	II January 7 Average Mgs. N.	III January 28 Nitrate Mgs. N.	III January 28 Average Mgs. N.	IV February 12 Nitrate Mgs. N.	IV February 12 Average Mgs. N.	V February 26 Nitrate Mgs. N.	V February 26 Average Mgs. N.	VI March 12 Nitrate Mgs. N.	VI March 12 Average Mgs. N.
1	1	20.41	20.62	19.74	19.36	17.04	17.04	20.83	21.13	22.06	21.90	24.19	23.79
	2	20.83		19.99		17.04		21.43		21.74		23.40	
2	3	20.83	20.83	18.99	19.36	17.04	16.94	19.74	20.58	20.27	21.16	24.57	23.98
	4	20.83		19.74		16.85		21.43		22.06		23.40	
3	5	20.83	21.53	20.00	19.87	18.99	18.99	18.75	19.17	22.06	21.90	28.47	25.43
	6	21.23		19.74		18.99		19.59		21.74		22.40	
4	7	21.73	21.48	20.00	19.87	18.52	17.68	20.00	19.87	22.06	22.06	22.40	24.13
	8	21.23		19.59		16.85		19.74		22.06		25.86	
5	9	22.22	22.46	22.06	22.23	16.48	16.48	22.39	21.91	22.06	22.22	25.86	26.81
	10	22.72		22.40		16.48		21.43		22.39		27.77	
6	11	20.41	21.07	23.81	24.00	18.52	17.50	19.23	20.43	22.73	22.08	25.42	26.59
	12	21.73		24.19		16.48		21.74		21.43		27.77	
7	13	21.73	21.73	22.73	22.56	15.96	16.90	22.73	23.06	22.40	23.48	26.31	24.85
	14	21.73		22.39		16.85		23.40		24.57		23.40	
8	15	22.22	22.47	21.74	22.07	16.85	16.94	20.27	20.27	21.74	23.15	27.77	25.98
	16	22.72		22.40		17.04		20.27		24.57		24.19	
9	17	20.83	21.03	21.13	20.98	17.04	16.94	20.55	20.55	22.73	21.23	23.81	23.10
	18	21.23		20.83		16.85		20.55		19.74		22.40	
10	19	21.23	21.03	21.13	21.13	17.04	16.94	18.07*	......	22.06	22.06	26.31	25.06
	20	20.83		21.13		16.85		17.65*		18.75*		23.81	
11	21	20.83	21.03	20.27	20.37	17.65	17.32	18.99	19.91	22.06	21.16	25.42	25.86
	22	21.23		20.48		16.99		20.83		20.27		26.31	
12	23	21.23	21.03	18.75	18.87	18.07	17.01	20.27	21.16	22.06	22.06	25.42	23.91
	24	20.83		18.99		15.96		22.06		19.23*		22.40	
13	25	20.41	20.62	22.06	21.90	16.85	16.94	18.07*	20.27	20.00	20.13	25.42	24.61
	26	20.83		21.74		17.04		20.27		20.27		23.81	
14	27	20.83	20.83	22.06	21.90	16.66	17.05	19.74*	21.43	22.06	21.90	25.00	24.78
	28	20.83		21.74		17.44		21.43		21.74		24.57	
15	29	21.23	21.48	25.64	25.61	18.99	18.87	22.73	22.56	22.73	23.27	27.27	26.34
	30	21.73		24.59		18.75		22.40		23.81		25.42	
16	31	21.23	21.23	25.86	25.64	19.48	19.00	22.40	23.10	24.19	23.79	27.27	26.56
	32	21.23		25.42		18.52		23.81		23.40		25.86	
17	33	21.23	21.48	23.81	23.60	18.52	17.78	20.55	21.64	22.39	21.47	27.77	26.59
	34	21.73		23.40		17.04		22.73		20.55		25.42	
18	35	21.23	21.72	23.40	23.40	18.52	18.08	23.40	21.70	24.19	22.51	26.78	27.27
	36	22.22		23.40		17.65		20.00		20.83		27.77	

* Results omitted from the averages.

pected that the effects would be in the same direction for both processes. It is possible, however, that different materials might increase both processes, but to different degrees.

It is important to note, however, from these results that the common humus-forming materials, such as are used on the farm, when applied in maximum amounts did not depress the nitrifying power of the soil, at least of this particular soil. On the other hand, there was an increase in nitrification to a more or less pronounced extent with the different materials. In the case of soils containing more organic matter, or material of a nar-

TABLE VIII. THE NITRIFICATION OF AMMONIUM SULFATE

Pot No.	Treatment	I		II		III	
		Nitrate Mgs. N.	Average Mgs. N.	Nitrate Mgs. N.	Average Mgs. N.	Nitrate Mgs. N.	Average Mgs. N.
1	Check	20.62		19.36		17.04	
2	Check	20.83	20.72	19.36	19.36	16.94	16.99
3	Horse manure...	21.53		19.87		18.99	
4	Horse manure...	21.48	21.50	19.78	19.82	17.68	18.33
5	Cow manure.....	22.46		22.23		16.48	
6	Cow manure.....	21.07	21.76	24.00	23.11	17.50	16.99
7	Rotted manure...	21.73		22.56		16.90	
8	Rotted manure...	22.47	22.10	22.07	22.31	16.94	16.92
9	Oats straw.......	21.03		20.98		16.94	
10	Oats straw.......	21.03	21.03	21.13	21.05	16.94	16.94
11	Corn stover......	21.03		20.37		17.32	
12	Corn stover......	21.03	21.03	18.87	19.62	17.01	17.16
13	Timothy hay.....	20.62		21.90		16.94	
14	Timothy hay.....	20.83	20.72	21.90	21.90	17.05	16.99
15	Cowpea hay......	21.48		25.61		18.87	
16	Cowpea hay......	21.23	21.35	25.64	25.62	19.00	18.93
17	Clover hay.......	21.48		23.60		17.78	
18	Clover hay.......	21.72	21.60	23.40	23.50	18.08	17.93

Pot No.	Treatment	IV		V		VI	
		Nitrate Mgs. N.	Average Mgs. N.	Nitrate Mgs. N.	Average Mgs. N.	Nitrate Mgs. N.	Average Mgs. N.
1	Check	21.13		21.90		23.79	
2	Check	20.58	20.85	21.16	21.53	23.98	23.88
3	Horse manure...	19.17		21.90		25.43	
4	Horse manure...	19.87	19.52	22.06	21.98	24.13	24.78
5	Cow manure.....	21.91		22.22		26.81	
6	Cow manure.....	20.43	21.17	22.08	22.15	26.59	26.70
7	Rotted manure...	23.06		23.48		24.85	
8	Rotted manure...	20.27	21.66	23.15	23.31	25.98	25.91
9	Oats straw.......	20.55		21.23		23.10	
10	Oats straw.......	.....	20.55	22.06	21.64	25.06	24.08
11	Corn stover......	19.91		21.16		25.86	
12	Corn stover......	21.16	20.53	22.06	21.61	23.91	24.88
13	Timothy hay.....	20.27		20.13		24.61	
14	Timothy hay.....	21.43	20.85	21.90	21.01	24.78	24.69
15	Cowpea hay......	22.56		23.27		26.34	
16	Cowpea hay......	23.10	22.83	23.79	23.53	26.56	26.45
17	Clover hay.......	21.64		21.47		26.59	
18	Clover hay.......	21.70	21.67	22.51	21.99	27.27	26.93

rower nitrogen-carbon ratio, it is difficult to predict the effect, but inasmuch as organic matter in such large amounts as were used here, particularly in the case of the leguminous green manures, would not be used unless the soils were low in nitrogen, it seems safe to say that there is no danger of restricting nitrification in soils by additions of amounts of organic matter such as would be used in the field.

In general from these experiments it is apparent that nitrification was increased by additions of organic materials, such as are made on the farm, and these increases were independent of the nitrogen-carbon ratio in the materials, although there were some indications that the materials of a narrower ratio gave a greater effect than those of a wider ratio, but the results were not conclusive. Inasmuch as the latter possibility is the opposite of the case with ammonification, it is apparent that more definite results must be secured before any conclusions should be drawn.

THE AZOFICATION EXPERIMENTS

The samples drawn on the six dates mentioned previously were tested for their azofying or nitrogen-fixing power by the fresh-soil method. At the first sampling, mannite (5 gms. per 100 grams of soil) was used and at the later dates dextrose was employed, being added from solution at the rate of 3 grams per 100 grams of soil.

The incubation period was 11 days, except in the case of the second sampling when the tests were allowed to incubate 14 days. The complete results of the tests are given in table IX and the summarized results appear in table X.

As might be expected, there were considerable variations in the results of the duplicate determinations. The method used for the determination of total nitrogen does not permit of the estimation of such small amounts of nitrogen as sometimes represent the nitrogen fixation. In some instances a smaller amount of nitrogen was actually found after the incubation period but it was hardly possible for any loss of nitrogen to occur and hence such results should be attributed to the fact that the method is not accurate for small amounts of nitrogen. These low results are eliminated from the averages and are interpreted merely as representing, therefore, the absence of any azofication.

In calculating the results, the total nitrogen present in the soils in the tests before incubation was estimated and subtracted from the nitrogen present at the end to determine the amount of nitrogen fixed. A slight error is, of course, introduced here in case not all of the mannite or dextrose added was used by the bacteria. Then the unused portion would be included in the sample analyzed after incubation. In such a case the results would be slightly lower than they should be, hence the amounts

TABLE IX. AZOFICATION

Pot No.	Lab. No.	N. in Orig. Soil Mgs.	I December 24 N. after incub. Mgs.	I December 24 N. fixed Mgs.	I December 24 Average Mgs.	II January 7 N. after incub. Mgs.	II January 7 N. fixed Mgs.	II January 7 Average Mgs.	III January 28 N. after incub. Mgs.	III January 28 N. fixed Mgs.	III January 28 Average Mgs.	IV February 12 N. after incub. Mgs.	IV February 12 N. fixed Mgs.	IV February 12 Average Mgs.	V February 26 N. after incub. Mgs.	V February 26 N. fixed Mgs.	V February 26 Average Mgs.	VI March 12 N. after incub. Mgs.	VI March 12 N. fixed Mgs.	VI March 12 Average Mgs.
1	1	98.80	99.50	.70		110.10	11.30		102.03	3.50		102.30	3.50		103.70	4.90		106.50	7.70	
	2	98.80	98.80	.00	.35	110.20	1.40	6.35	111.50	12.70	8.10	100.90	2.10	2.80	100.90	2.10	3.50	105.10	6.30	7.00
2	3	98.80	102.30	3.50		104.40	5.60		105.80	7.00		98.80	.00		103.70	4.90		105.80	7.00	
	4	98.80	100.90	2.10	2.80	105.80	7.00	6.30	104.40	5.60	6.30	107.20	8.40	4.20	103.00	4.20	4.55	107.20	8.40	7.70
3	5	106.56	110.80	4.24		115.70	9.14		122.10	15.54		110.80	4.24		108.60	2.04		117.10	10.54	
	6	106.56	107.20	.64	2.44	115.70	9.14	9.14	116.40	9.84	12.69	107.90	1.34	2.79	110.10	3.54	2.79	118.50	11.94	11.24
4	7	106.56	107.20	.64		115.00	8.44		116.40	9.84		112.20	5.64		107.20	.66		115.00	8.44	
	8	106.56	105.10	-1.46*	.64	115.70	9.14	8.79	115.70	9.14	9.49	109.40	2.84	4.24	115.70	9.14	4.70	118.50	11.94	10.19
5	9	107.62	110.10	2.48		119.90	12.28		121.30	13.68		111.50	3.88		111.50	3.88		118.50	10.88	
	10	107.62	111.50	3.88	3.18	115.00	7.38	9.83	117.10	9.48	11.58	117.80	10.18	7.03	119.90	12.28	8.08	125.60	17.98	14.43
6	11	107.62	110.10	2.48		118.50	10.88		108.20	-.42*		115.00	7.38		119.90	12.28		120.60	12.98	
	12	107.62	111.50	3.88	3.18	115.70	8.08	9.48	119.20	11.58	11.58	111.50	3.88	5.63	112.90	5.28	8.78	115.70	8.08	10.53
7	13	111.32	111.50	.18		117.80	6.48		117.10	5.78		115.70	4.38		115.00	3.68		115.00	3.68	
	14	111.32	111.50	.18	.18	122.80	11.48	8.98	120.60	9.28	7.53	112.90	1.58	2.98	115.70	4.38	4.03	127.70	16.38	10.03
8	15	111.32	105.80	-5.52*		119.90	8.58		122.80	11.48		121.30	9.98		113.60	2.28		122.80	11.48	
	16	111.32	113.60	2.28	2.28	121.40	10.08	9.33	131.20	19.88	10.68	115.70	4.38	7.18	118.50	7.18	4.73	127.00	15.68	13.58
9	17	100.97	104.40	3.43		105.80	4.83		112.20	11.23		115.70	14.73		108.60	7.63		106.50	5.53	
	18	100.97	107.20	6.23	3.83	104.40	3.43	4.13	112.90	11.93	11.58	111.50	10.53	12.63	108.60	7.63	7.63	108.60	7.63	6.58
10	19	100.97	100.20	-.77*		112.90	11.93		117.10	16.13		104.40	3.43		105.10	4.23		104.40	3.43	
	20	100.97	101.50	.53	.53	108.60	7.63	9.78	112.90	11.93	14.03	107.20	6.23	4.83	111.50	10.53	7.38	112.90	11.93	7.66
11	21	103.23	105.80	2.57		109.40	6.17		107.20	3.97		108.60	5.37		107.20	3.97		111.50	8.27	
	22	103.23	107.90	4.67	3.62	111.50	8.27	7.22	105.80	2.57	3.27	104.40	1.17	3.27	110.10	6.87	5.42	106.50	3.27	5.77
12	23	103.23	100.90	2.33		108.60	5.37		111.50	8.27		112.90	9.67		107.90	4.67		109.40	6.17	
	24	103.23	106.50	3.27	2.80	111.50	8.27	6.82	109.40	6.17	7.22	107.90	4.67	7.17	110.80	7.57	6.12	110.10	6.87	6.52
13	25	100.75	103.00	2.25		105.80	5.05		105.80	5.05		104.40	3.65		107.20	6.45		105.80	5.05	
	26	100.75	105.10	4.35	3.30	114.30	13.55	9.30	104.40	3.65	4.35	108.60	7.85	5.75	104.40	3.65	5.05	112.90	12.15	8.60
14	27	100.75	102.30	1.55		108.60	7.85		103.00	2.25		106.50	5.75		107.20	6.45		110.10	9.35	
	28	100.75	107.20	6.45	4.00	109.40	8.65	8.25	108.60	7.85	5.05	104.40	3.65	4.70	112.90	12.15	9.30	109.40	8.65	9.00
15	29	107.55	108.60	1.05		112.20	4.65		112.90	5.35		110.10	2.55		113.60	6.05		108.60	1.05	
	30	107.55	107.20	-.35*	1.05	112.90	5.35	5.00	115.00	7.45	6.40	105.10	-2.45*	2.55	107.20	-.35*	6.05	110.10	2.55	1.80
16	31	107.55	107.20	-.35*		111.50	3.95		116.40	8.85		112.90	5.35		110.10	2.55		108.60	1.05	
	32	107.55	107.20	-.35*	.....	112.20	4.65	4.30	112.20	4.65	6.75	112.20	4.65	5.00	107.90	.35	1.45	112.20	4.65	2.85
17	33	107.03	110.10	3.07		111.50	4.47		113.60	6.57		110.80	3.77		110.10	3.07		109.40	2.37	
	34	107.03	103.00	-4.03*	3.07	108.60	1.57	3.02	114.30	7.27	6.92	108.60	1.57	2.67	111.50	4.47	3.77	110.10	3.07	2.72
18	35	107.03	108.00	.97		112.90	5.87		108.60	1.57		112.90	5.87		110.10	3.07		112.20	5.17	
	36	107.03	107.20	.17	.57	115.70	4.47	5.17	111.50	4.47	3.02	110.10	3.07	4.47	111.50	4.47	3.77	109.40	2.37	3.77

* Results omitted from the averages.

of nitrogen fixed from the atmosphere may be too low but that fact need not interfere with the interpretation of the results.

Considering the results given in table X, it is apparent that the addition of various organic materials to the soil influenced to a considerable extent the fixation of nitrogen by non-symbiotic bacteria. In some cases the amount of nitrogen fixed in the 11-day incubation period amounted to one-sixth of the nitrogen originally present in the soil.

The soils receiving cow manure and oats straw showed for the most part the greatest increase in azofying power and the influ-

TABLE X. AZOFICATION

Pot No.	Treatment	I		II		III	
		N. fixed Mgs.	Average Mgs.	N. fixed Mgs.	Average Mgs.	N. fixed Mgs.	Average Mgs.
1	Check	.35		6.35		8.10	
2	Check	2.80	1.57	6.30	6.32	6.30	7.20
3	Horse manure...	2.44		9.14		12.69	
4	Horse manure...	.64	1.54	8.79	8.96	9.49	11.09
5	Cow manure.....	3.18		9.83		11.58	
6	Cow manure.....	3.18	3.18	9.48	9.65	11.58	11.58
7	Rotted manure...	.18		8.98		7.53	
8	Rotted manure...	2.28	1.23	9.33	9.15	10.68	9.10
9	Oats straw.......	3.83		4.13		11.58	
10	Oats straw.......	.53	2.18	9.78	6.95	14.03	12.80
11	Corn stover......	3.62		7.22		3.27	
12	Corn stover......	2.80	3.21	6.82	7.02	7.22	5.24
13	Timothy hay.....	3.30		9.30		4.35	
14	Timothy hay.....	4.00	3.85	8.25	8.77	5.05	4.70
15	Cowpea hay......	1.05		5.00		6.40	
16	Cowpea hay......	....	1.05	4.30	4.65	6.75	6.57
17	Clover hay.......	3.07		3.02		6.92	
18	Clover hay.......	.57	1.82	5.17	4.09	3.02	4.97

Pot No.	Treatment	IV		V		VI	
		N. fixed Mgs.	Average Mgs.	N. fixed Mgs.	Average Mgs.	N. fixed Mgs.	Average Mgs.
1	Check	2.80		3.50		7.00	
2	Check	4.20	3.50	4.55	4.02	7.70	7.35
3	Horse manure...	2.79		2.79		11.24	
4	Horse manure...	4.24	3.51	4.70	3.74	10.19	10.71
5	Cow manure.....	7.03		8.08		14.43	
6	Cow manure.....	5.63	6.33	8.78	8.43	10.53	12.48
7	Rotted manure..	2.98		4.03		10.03	
8	Rotted manure..	7.18	5.08	4.73	4.38	13.58	11.80
9	Oats straw.......	12.63		7.63		6.58	
10	Oats straw.......	4.83	8.73	7.38	7.50	7.66	7.12
11	Corn stover......	3.27		5.42		5.77	
12	Corn stover......	7.17	5.19	6.12	5.79	6.52	6.14
13	Timothy hay.....	5.75		5.05		8.60	
14	Timothy hay.....	4.70	5.22	9.30	7.17	9.00	8.80
15	Cowpea hay......	2.55		6.05		1.80	
16	Cowpea hay......	5.00	3.77	1.45	3.75	2.85	2.32
17	Clover hay.......	2.67		3.77		2.72	
18	Clover hay.......	4.47	3.57	3.77	3.77	3.77	3.24

ence of the rotted manure was only slightly less than that of the cow manure.

The horse manure gave less effect than the other manures and abount the same in most cases as the timothy hay. The corn stover also affected the azofying power of the soil to about the same extent as the horse manure.

The cowpea hay and the clover hay exerted the smallest effect of any of the materials on the azofying power of the soil.

It appears, therefore, from the results as a whole that the nitrogen-carbon ratio of the various humus-forming materials applied to the soil was of little significance from the standpoint of the effect on azofication. The influence of the materials was exerted regardless of the nitrogen-carbon ratio. Thus the oats straw of a wide ratio and the cow manure of a narrower ratio had about the same effect. Similarly the timothy hay and the horse manure of wide and narrow ratios respectively had considerable influence. Again the rotted manure of a very narrow ratio exercised as much effect on azofication as the timothy hay which had a wide ratio.

To just what influence of the materials the difference in results was due is difficult to determine. It may be that the difference in chemical composition of the substances explains the results. This was the conclusion reached in the ammonification and nitrification experiments and would probably hold true here. It is well known that organic compounds of different composition exert quite different effects on the azotobacter and hence the results from the use of the materials employed here might be expected, to the extent at least that the different materials had various effects. The important point in this connection which these results bring out is that the character of the compounds present apparently determined the results and the ratio of the nitrogen to carbon present gave no indication of the effects to be expected.

It is interesting to note further that the leguminous hays had much less effect on the azofying power of the soil than the other materials. Especially is this point worthy of mention because of the relative effects of the legumes and non-legumes as green manures. If the latter materials will increase the fixation of nitrogen from the atmosphere by the non-symbiotic azotobacter sufficiently to supply as much nitrogen for the use of crops as is added in legume crops, such materials might frequently be preferable for use on soils. It is impossible from these results to ascertain whether such is the case or not. Further results must be secured with complete field experiments before definite conclusions can be reached.

These results do show, however, that the non-legumes increased the azofying power of the soil to a much greater extent than the legumes. This greater effect was probably due as has been mentioned to the chemical composition of the materials. In this case the effects are in the same direction as the widening of the nitrogen-carbon ratio, and it might seem that the ratio of the materials would indicate the influence on azofication, but inasmuch as the manures of narrower nitrogen-carbon ratio had as much effect as the non-legumes and straws it would evidently not be warranted to draw any conclusion regarding the effects of the ratio in materials added on azofication.

In general, then, the results show that azofication was favored by manure to a large extent; that straw, stover, and non-leguminous hays had almost as great an effect as the manures, altho of a much wider nitrogen-carbon ratio, and that the leguminous hays had the least effect of any of the materials used in the experiment. Apparently the nitrogen-carbon ratio of the materials used was of little or no significance in indicating their influence on azofication and differences in effects were due rather to variations in the chemical compounds present.

There are indications, however, that non-leguminous hays and straws may increase azofication in soils to a large enough extent to make their use more profitable than that of legumes which altho adding nitrogen to the soil are somewhat more expensive to use.

These conclusions apply, of course, as must be emphasized again, only to this particular soil type and when the materials are used in amounts such as are employed here, that is, in maximum field applications. The results are, therefore, directly applicable to farm conditions on this soil type and may indicate what will occur on similar soils. Further experiments on the comparative effects of legumes and non-legumes as green manures from the standpoint of their influence on azofication are extremely desirable and may lead to important practical conclusions.

One point further is worthy of mention in connection with these experiments and that is that the results secured with dextrose were much more satisfactory than those with mannite. The latter material has been considered the best for such work, but it is possible that the cheaper dextrose may serve as well or even better. The point is worthy of consideration in connection with extensive azofication experiments.

Comparing the azofication results as a whole with the ammonification and nitrification results, it appears that there was little similarity in the effects of the different materials on the different processes. Azofication was increased in some cases to a greater extent by some materials than by others, whereas the opposite was the case with ammonification and nitrification.

This fact brings up another important point in connection with the use on soils of organic materials which increase azofication to the greatest extent. Is it necessary that ammonification and nitrification should also be considered? This is a question which must be left for future rather extensive experiments to settle, and involves the whole question of the form in which plants may assimilate their nitrogen, a question which is apparently far from definitely settled as yet.

THE CROP YIELDS

The crop of oats on the pots, the duplicates of which were kept bare for bacteriological tests, was harvested just prior to maturity, dried, ground, and analyzed for total nitrogen. The green and dry weights of the crop are given in table XI and the nitrogen content of the crop together with the calculated removal of nitrogen from the soil are given in table XII.

TABLE XI. THE CROP YIELDS

Pot No.	Treatment	Green Weight Gms.	Average Gms.	Dry Weight Gms.	Average Gms.
19	Check	189.0		58.6	
20	Check	207.0	198.00	61.5	60.05
21	Horse manure..	112.9		30.3	
22	Horse manure..	119.7	116.30	32.0	31.15
23	Cow manure....	234.4		70.6	
24	Cow manure....	218.2	226.30	63.0	66.80
25	Rotted manure.	279.6		85.2	
26	Rotted manure.	298.4	289.00	88.9	87.05
27	Oats straw.....	115.3		32.5	
28	Oats straw.....	100.6	107.95	28.9	30.70
29	Corn stover....	182.9		50.0	
30	Corn stover....	180.7	181.80	52.6	51.30
31	Timothy hay...	143.2		44.6	
32	Timothy hay...	151.1	147.15	45.3	44.95
33	Cowpea hay.....	260.5		72.4	
34	Cowpea hay.....	244.6	252.55	72.8	72.60
35	Clover hay.....	224.9		63.6	
36	Clover hay.....	224.9	224.90	64.0	63.80

Examining the yields in table XI, it appears that the rotted manure, the cow manure, and the leguminous hays increased the crop yields to a considerable extent. The horse manure depressed the yield over that of the untreated soil. The plants in these pots were weak and turned yellow soon after they appeared above the surface of the soil, but after about ten weeks this bad effect from the horse manure disappeared and the oats showed a more vigorous growth. If the experiment had continued longer, it is probable that the yields would have equaled those secured with the other materials. The depressing action was probably due to the introduction with the heavy application of manure of chemical substances which were injurious to the young plants.

All of the non-legume hays, straw, and stover materials with a wide nitrogen-carbon ratio gave no gain in the crop yields. In fact, an actual depression in yields occurred. These materials apparently did not decompose sufficiently rapidly to aid the crop grown or the nitrogen content of the soil was more depleted than was believed. At any rate, the legume hays increased the yields, which would indicate that the nitrogen factor on these soils was important and that the non-legumes did not increase the fixation of nitrogen from the atmosphere sufficiently to keep the oats supplied with that element.

The experiment, of course, was hardly continued long enough for definite crop results to be secured and a second crop was planted after the first was removed in order to determine whether different results would be secured, allowing a longer time for the organic material to decompose.

It appears from these first results, however, that the nitrogen-carbon ratio of the organic materials was of considerable significance in determining the effects of the materials used on the crop yields from this particular soil. In every case those substances with the narrower nitrogen-carbon ratios increased to the greatest extent the crop yields, while the materials of wide ratios decreased the crop yields. The nitrogen factor was evidently very important on this particular soil.

In table XII, it is seen that the percentage of nitrogen in the oats varied considerably, the tendency being for the lowest yields to show the highest nitrogen content. The largest crops, however, removed the greatest amount of nitrogen from the soil.

The crop yields as a whole show that materials such as were used in this work may exert a considerable influence on bacterial activities and not show the same effect on the crop grown. The

TABLE XII. THE ANALYSES OF THE CROPS

Pot No.	Treatment	N. in Crop Per cent	Average Per cent	C. in Crop Per cent	Average Per cent	N—C Ratio	N. removed Gms.	Average Gms.
19	Check	.734		39.429			.430	
20	Check	.730	.732	37.637	38.533	1 : 52.64	.449	.439
21	Horse manure	.818		41.911			.248	
22	Horse manure	.861	.839	37.083	39.497	1 : 47.07	.276	.262
23	Cow manure	.734		45.827			.518	
24	Cow manure	.734	.734	45.372	45.599	1 : 62.11	.462	.490
25	Rotted manure	.776		40.413			.661	
26	Rotted manure	.797	.786	37.367	38.890	1 : 49.48	.709	.685
27	Oats straw	.764		38.745			.248	
28	Oats straw	.771	.767	39.140	38.943	1 : 50.77	.224	.236
29	Corn stover	.783		39.195			.392	
30	Corn stover	.797	.790	37.254	38.225	1 : 48.37	.419	.405
31	Timothy hay	.709		38.653			.316	
32	Timothy hay	.703	.706	39.985	39.319	1 : 55.69	.318	.317
33	Cowpea hay	.903		38.372			.654	
34	Cowpea hay	.868	.885	38.808	38.590	1 : 43.60	.632	.643
35	Clover hay	.805		42.410			.512	
36	Clover hay	.836	.820	44.443	43.427	1 : 52.96	.534	.523

effects on subsequent crops, however, would be a more definite indication of the relative values of these materials, because of the need of time for decomposition. In other words, it would not be expected that the effects of such materials on crops would be exerted as soon as effects on bacterial activities. The latter must always precede the former. Hence some time should elapse after applying organic materials before the effect on the crop grown is determined. If the effects of materials of wide nitrogen-carbon ratio are dependent to any extent on the increase in nitrogen content of the soil through non-symbiotic nitrogen-fixation, time should be allowed for this process to occur before the comparative effects on crop yields are tested. It is not regarded, therefore, that these crop yields present facts which oppose in any way the possibility of sufficient azofication occurring in soils treated with non-legumes to equal the effects caused by legumes.

THE SECOND CROP YIELDS

The second crop of oats grown on the same soils as in the case of the first crop was harvested before it had attained any considerable growth. The yields given in table XIII, however, show some interesting relations to those of the first crop.

In this case, all the treatments increased the oats growth but the horse and cow manures gave the largest effect here, while the rotted manure gave a smaller effect than any of the other materials. With the first crop, the rotted manure gave the greatest influence, while the cow manure hardly increased the yield and the horse manure depressed the oats growth. Evidently the cause of the injurious action of the horse manure had disappeared before the second crop was grown, and only beneficial effects from the material were in evidence on the second crop.

TABLE XIII. THE SECOND CROP YIELDS

Pot No.	Treatment	Green Weight Gms.	Average Gms.	Dry Weight Gms.	Average Gms.
19	Check	26.7		6.5	
20	Check	32.3	29.50	7.7	7.1
21	Horse manure..	47.7		11.6	
22	Horse manure..	57.0	52.35	12.7	12.15
23	Cow manure....	49.9		12.8	
24	Cow manure....	57.95	53.92	15.0	13.9
25	Rotted manure.	34.0		7.4	
26	Rotted manure.	39.5	36.75	9.2	8.3
27	Oats straw.....	41.7		10.0	
28	Oats straw.....	49.55	45.62	12.2	11.1
29	Corn stover....	56.65		11.5	
30	Corn stover....	43.2	49.92	10.0	10.75
31	Timothy hay...	38.6		7.0	
32	Timothy hay...	43.4	41.00	11.2	9.1
33	Cowpea hay....	37.3		9.0	
34	Cowpea hay....	51.1	44.20	12.2	10.6
35	Clover hay.....	44.5		9.5	
36	Clover hay.....	41.15	42.82	9.5	9.5

The rotted manure had apparently lost much of its value for increasing the crop yield by the time the first crop was removed, and had little effect on the second crop.

The oats straw and corn stover gave greater yield than the legume hays and the timothy hay had only a slightly smaller effect than the clover and cowpeas. It is apparent, therefore, that the conclusion drawn in connection with the first yields was well warranted. The non-legumes here seemed to have a greater or as great an effect on the crop as the legumes. Evidently the nitrogen fixed by azofiers was sufficient to supply the second crop of oats with as much of that element as was furnished by the legumes. Of course, there was probably some neutralizing action here as might be expected. If the first crop of oats took out much more nitrogen where the legumes were used than where the other materials were applied, the second crop might be not as well supplied as in the case of the non-legumes because of a shortage of nitrogen. Such could hardly be the case here, however, to more than a negligible extent and hence the conclusion seems justified that non-legumes may be as beneficial as legumes on crops grown, provided sufficient time is allowed to elapse between the application of the materials and the growth of the crop, for decomposition to occur and the fixation of nitrogen from the atmosphere to take place.

There is much closer agreement between the effects of the various materials on bacterial activities and on the second crop of oats than with the first crop. It will be recalled that the first crop of oats was seeded as soon as the substances were added, and it would appear from these results that the influence of many of these common humus-forming substances on crops is much greater if time is allowed for decomposition and other affected bacterial processes to occur before the crow is grown.

The nitrogen-carbon ratio of the various substances did not seem to be of as much importance in determining their effect on the second crop of oats as with the first crop, although there were indications that the materials with wider ratios had more effect than those with narrower ratios.

SUMMARY

The results of these experiments on this particular soil type lead to the following conclusions.

1. Applications of the common humus-forming materials in maximum amounts for farm conditions and in a dried condition increased bacterial activities, ammonification, nitrification, and azofication to a considerable extent.

2. The manures, horse manure, cow manure, and rotted manure gave the greatest effect on ammonification in most cases, altho timothy hay surpassed the horse manure and cow manure

in the extent of its effect in several instances. The oats straw and corn stover gave a smaller effect than the manures and the legume hays, clover, and cowpeas showed the least effect on ammonification of any of the materials used.

3. Increases in ammonification due to the applications of humus-forming materials were independent of the nitrogen-carbon ratio of the materials added and were probably dependent on the chemical composition of the substances.

4. The relative effects of the various materials used would undoubtedly be somewhat altered for field conditions, because of the fact that they were applied in a dried condition. Especially in the case of the manures would the influence on ammonification be accentuated because of the actual addition of bacteria to the soil.

5. The dried-blood-fresh-soil method gave better results for ammonification than the casein-fresh-soil method. The latter gave better duplicate results, but the differences between different soils were not nearly so pronounced. Some further modification of the casein method seems necessary for its general use.

6. Nitrification was increased in much the same way as ammonification, by the various organic materials. The leguminous green manures exerted, however, somewhat greater effects than the manures, and also more influence than the non-legumes. These results were the opposite of those secured with ammonification, but the differences were not great enough to permit of definite conclusions.

7. Increases in nitrification brought about by the various materials were apparently independent of the nitrogen-carbon ratio in the substances. Indications of a greater effect of materials of a narrower ratio over those of a wide ratio cannot be considered conclusive.

8. Azofication or non-symbiotic nitrogen fixation was favored by manure to a large extent. Straw, stover, and non-leguminous hays had almost as great an effect as the manures and the leguminous hays had the least effect of any of the materials used.

9. The nitrogen-carbon ratio of the materials employed were of little or no significance in indicating their effects on azofication. There were indications, however, that non-legumes and straws might increase azofication in soils to a large enough extent to make their use more profitable than that of legumes which add nitrogen to the soil but are somewhat more expensive to use.

10. Further experiments carried on under field conditions to ascertain the relative effects of legumes and non-legumes on azofication are extremely desirable and results secured may be of great practical importance.

11. Dextrose gave better results in the azofication experi-

ments than mannite and may, therefore, be substituted for the more expensive material.

12. There was little similarity between the effects of the different organic materials on the different bacterial processes. Is it necessary that the material which increases ammonification, nitrification, and azofication be chosen for use in soils, or shall an increase in azofying power be sufficient to recommend the substance? This question cannot yet be answered.

13. The manures and legumes increased the first crop of oats, except in the case of the horse manure, which apparently exerted an injurious effect on the crop in its early stages of growth. This injury was disappearing and might have been unnoticed had the crop been grown for a longer period.

14. The substances with wide nitrogen-carbon ratio decreased the crop yield while those of narrow ratios gave increases. The nitrogen factor was evidently very important on this soil.

15. The nitrogen-carbon ratio of the organic materials did seem to be of importance in determining the influence on the first crop of oats.

16. If opportunity is to be given for non-legumes to exert as good an effect as legumes by increasing azofication to a sufficient extent to offset the nitrogen supplied by the legumes, the organic materials must be allowed sufficient time for considerable decomposition to occur before a crop is grown to test the effects.

17. The influence of the various substances applied to the soils was noted on a second crop of oats, but the relative effects were different. The non-legumes had as great an influence as the legumes and hence previous conclusions are confirmed that with the use of the former materials sufficient time must be allowed to elapse for azofication to occur if as beneficial effects are to be secured as with legumes.

18. The nitrogen-carbon ratio of the materials applied to the soil did not seem to be of as much importance in determining the effect on the second crop of oats as in the case of the first crop.